Annual Project Summary

DEEP BOREHOLE TENSOR STRAIN MONITORING, NORTHERN CALIFORNIA

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Dr. M.T. Gladwin, Chief Research Scientist
Dr. R.L.Gwyther, Research Geophysicist

Commonwealth Scientific and Industrial Research Organisation
2643 Moggill Rd., Pinjarra Hills, QLD 4069, AUSTRALIA
phone +617 3212 4562
fax +617 3212 4455

II
seismology, geodesy, borehole geophysics

Project Objectives and Approach

This project provides field observations contributing to an understanding of fault processes associated with earthquakes along the San Andreas and Hayward faults. Continuous high precision and high resolution borehole tensor strain data provide an essential complement to long baseline interferometry studies (limited to sampling intervals of weeks), GPS studies, and seismic characterisation of faults.

The project continues a program of maintenance and analysis of deep borehole tensor strain instrumentation initiated at San Juan Bautista in late 1983, expanded by three sites installed in the Parkfield area during December of 1986, by two sites deployed near the Hayward Fault in the San Francisco Bay region in 1992. These instruments consist of a three component plane strain module operating at a strain sensitivity of 10^{-10} and support data logging systems. As deployed to date they provide data sampling at 30 minute intervals for transmission via satellite for permanent archive purposes. The instruments provided by this project are unique in the program in that they provide continuous tensor strain data of high quality and sensitivity not achievable by any other instrumentation. These data form a critical complement to GPS and geodetic studies (see Figure 1) in assessing strain rates and consequent earthquake risk, as well as investigating fault processes associated with earthquake preparation and postseismic relaxation. Archived long term baseline data are available from *http://www.cat.csiro.au/dem/msg/straincal/straincal.html*. Data are made available in near real time in the USGS Menlo Park computer system (***thecove:/home/mick/QUICKCHECK***). These data supplement long baseline survey data, and permit real time monitoring for short term strain phenomena.

The **immediate objectives** of the project are

- Maintenance of uphole system integrity at 5 Northern Californian sites, with repair or production of replacement uphole electronics if necessary.
- Manual preparation of raw instrument data for permanent archive.

- Analysis of continuous unique low frequency shear strain data (30 minute samples) and modelling studies based on the constraints of these data
- Regular reporting and real time alert response as part of the Parkfield Prediction experiment.
- Archive of processed data for access by the earthquake studies community, and provision of near-real time automatically processed data for inclusion in publicly accessible web pages linked to the USGS web datasets.

The project is carried out in parallel with maintenance of two further sites (Pinon Flat and San Gabriel mountains) in Southern California.

Investigations & Results

Strain-creep events at Parkfield.:

At Parkfield, both borehole tensor strainmeters located close to the San Andreas fault (Eades and Frolich) observe complex aseismic strain events with a frequency of approximately 5 per year.

· The strain events are usually associated with nearby surface creep events

· The strain events at each site are predominantly self-similar, indicating a common shallow source patch (see Figure 1).

· The slip sources identified for EDT and FLT are not contiguous, but separated by a distance of 6 km.

· Many of the strain events at EDT and FLT are simultaneous, indicating a common regional stress causing slip on both patches at the same time

· A significant proportion of the strain events at EDT and FLT are not simultaneous, but rather, occur within 1 to 3 days of each other, indicating some regional strain propagation with a velocity of 2 km per day (see Figure 2). These propagation velocities occur in both a northwesterly and southeasterly directions.

· Some of the strain events have simple character, with strain offset and decay over some hours. Other strain events have more complex strain signatures, which are repeated in later events.

· We proposed (Fall AGU 2000) that there are characteristic shallow locked patches, which slip at irregular intervals in response to a deeper regional stress, which at times propagates in both NW and SE directions along the fault. Changes in this

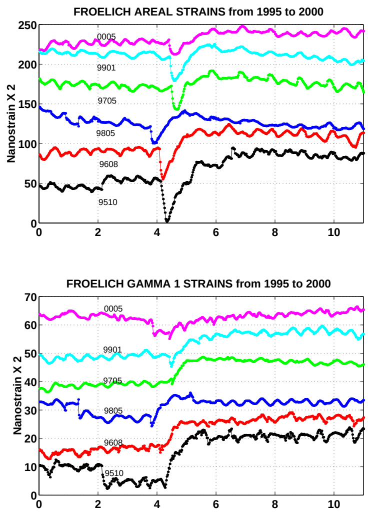

Figure 1. Examples of episodic strain events observed at Frolich site, over period 1995 to 2000.

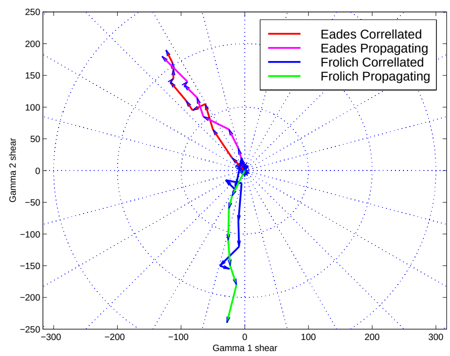

Figure 2. Direction of principal axes of shear strain = ½ azimuth of plotting Gamma1 against gamma2. Azimuths during episodic strain events at Frolich (135°) and at Eades (270°). There is relatively little scatter in these results.

regional stress are indicated by long term strain changes in 1993 (Gwyther et al., *GRL*, 1996) and 1997 (Gladwin et al., *EOS*, 1999).

Piecewise linear strain rates at Parkfield and San Juan Bautista.:

We now have sufficient baseline data from borehole strainmeters (up to 17 years), at transition zones at both ends of the central creeping section of the San Andreas fault, to conclude with some generality that strain changes in these regions are dominated by piecewise linear strain. The long term strain data from San Juan Bautista are shown in Figure 3 below and data from Parkfield are shown in Figure 4.

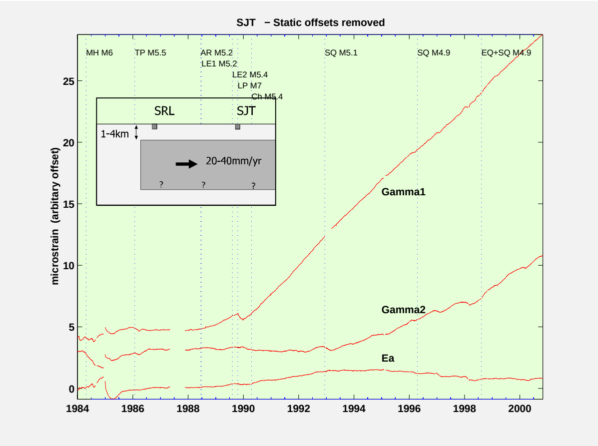

Figure 3. Long term strain data observed at San Juan Bauitista, showing linear strain rates between major events. Slip as shown on inset diagram results in dominant change in gamma1 shear observed.

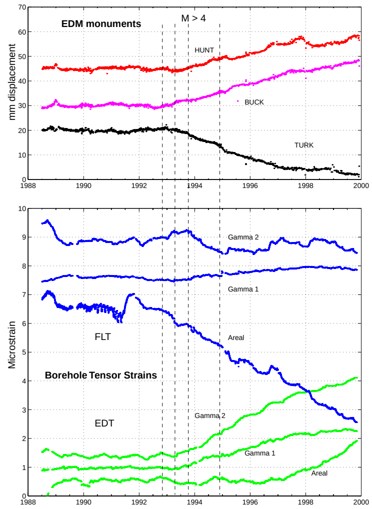

Figure 4. Long term strain data at Eades and Frolich, Parkfield, showing linear strain rates between events in 1993 and 1997. Data from laser EDM lines in the same locality are shown for comparison.

Apart from coseismic and slowquake strain offsets, the data time series can be divided into long intervals of remarkably uniform strain rate, with rapid transitions between intervals to new strain rates. The rate transitions typically correlate with major seismic or aseismic events on nearby faults, and are of order 1μstrain/year. The observations are corroborated by multiple borehole strainmeters and by supplementary observations from creepmeters and high resolution geodetics (two color laser).

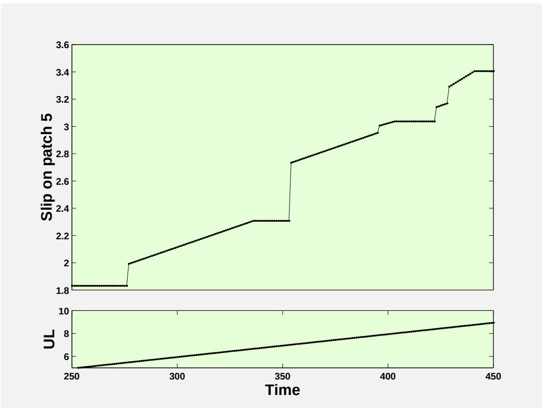

Figure 5. Model results of slip (upper plot) on a representative patch due to constant slip at depth (lower plot). Time behaviour such as this would result in linear strain rates observed in the region of the patch.

Preliminary results have been calculated from a simple model in which the stress to maintain steady slip against friction is produced interactively from the nett dislocation stress of all such creeping patches and the slip at depth (Hart et al., *EOS*, 2000). The model consists of 8 patches of fault of typical dimensions 3km to 5km (some of which fail by slow creep, and some fail in small earthquakes) are shown in Figure 5. The data and model suggest that the processes observed may be key components of stress migration at transition zones. A paper detailing the modeling results is currently in preparation.

Data Availability

Archived strain data from the Californian sites is stored in both raw component form, and as processed areal and shear strains. A regularly updated archive of data has been maintained in the USGS Menlo Park computer system since 1988. This data is stored in binary files with appended header information (USGS "*bottle*" format).

Home page for access to data plots from all borehole tensor strain instruments is *http://www.cat.csiro.au/dem/msg/straincal/straincal.html*. ***This page also includes facilities for download of raw or processed data from our CSIRO archive***.

Automatically processed near-realtime data is available in *thecove:/home/mick/QUICKCHECK* for users with access to USGS plotting software "*xqp*", and via the USGS crustal deformation web pages in graphical form.

Scientists requiring other access to the archived data should contact Dr. R. Gwyther (+617 3212 4586, email: *r.gwyther@cat.csiro.au*) or Dr. M.T. Gladwin (+617 3212 4562).

Publications

Publications 2000

Gwyther R.L., M.T. Gladwin, R.H. Hart & M.Mee Sharpening our Image of Fault Processes: what Borehole Tensor Strain Observations can add to Seismic and Geodetic Studies. *Seis. Res. Lett.* 70(1), 255, 2000.

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Gwyther, R.L., C.H. Thurber, M.T.Gladwin &M. Mee Seismic and Aseismic Observations of the 12th August 1998 San Juan Bautista, California M 5.3 earthquake, *Proc. 3rd Conf. on Tectonic Problems of the San Andreas Fault*, 2000

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Langbein, J., Gladwin, M.T., & Gwyther,R.L., Extension of the Parkfield deformation array,*Proc. 2nd Plate Boundary Observatory Workshop*,2.45-2.49,2000

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Gwyther R.L., M.T. Gladwin and R.H.G. Hart Anomalous Shear Strain at Parkfield During 1993-94 *Geophys. Res. Lett. V 23 (18)* p 2425-2428, 1996

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Non-Technical Summary

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